Preliminary Results of an Arrester Field Test at ComEd

By John McDaniel

Introduction

Lightning has been one of the leading reported cause of outages on the distribution system, at the 4kV and the 12kV voltage levels. This has been the case since ComEd began recording outages beginning in 1982. ComEd's experience is consistent with the results of a survey conducted by the IEEE, which found that 40 percent of all customer outages were due to lightning.

In 1992, a lightning protection study of the distribution system was conducted. The purpose of this study was to identify ways of improving the lightning performance of the distribution system. The study concluded that for a 12kV feeder, "by placing arresters every three spans (180m), reliability will be increased by more than 70% with only a 3.8% increase in cost." This 70% improvement was in the number of flashovers per year. Some of the assumptions for this study were: a 3-phase circuit length of 10 miles, a span length was 60m, 12.5m poles, ground resistance was 5 ohms, a 95 kV BIL (only the BIL of the insulators was taken into account), a ground flash density of 1.85 strikes/km^2 and no natural shielding. A recommendation of this study was that arresters should be installed every 180m on 4kV and 12kV feeders.

Lightning Arrester Field Test Program

In 1995, ComEd decided to conduct a field trial using the new lightning arrester standard. The objective of this field test was to verify the expected performance of the new lightning arrester standard. Sixty (60) 12 kV feeders with historically poor lightning performance were selected and broken into two (2) groups of thirty (30) feeders.

The two groups for the field test consisted of a control group and an experimental group. The experimental group would have lightning arresters installed to bring the entire feeder up to the new lightning arrester standard. Metal Oxide Varistor (MOV) lightning arresters were to be installed every 180m and all non-MOV arresters were to be replaced with MOV arresters. The control group would be left as is for comparison with the experimental group.

For selection of the feeders, interruption data from 1990 through 1994 was used. The feeders with the highest and most consistent number of lightning interruptions were chosen. These feeders were then ranked with the worst performer given the ranking of 1 and so on. By alternating the selection of these feeders for the control and experimental groups, the two groups included feeders with similar historical performance. In addition, the groups ended up being comparable in total length and in geographic distribution.

For the experimental group, installation of arresters began on 11/8/95. The installation of arresters was completed on the last of the feeders on 5/8/97. In all, approximately 40,000 arresters and 70,000 ground rods were installed on the 30 experimental feeders.

It should be noted that the condition of the experimental feeders varied vastly from the assumptions used in the 1992 Lightning Protection Analysis of the Distribution System study. For the experimental feeders, only 24% of the total length was 3-phase, while 21% was 2-phase and 55% was single phase. Also, the average pole height was less than that in the study, typical 10.5m poles for the 3-phase and 2-phase, while poles as short as 7.5m were found in some areas with single phase, while 9m to 10.5m poles were more the norm. The only condition that was the same was that the experimental feeders were mostly in open areas and would have a very low shielding factor. The computer analysis used a shielding factor of zero (0).

Analysis Methods

The method used to analyze the two (2) groups was to compare the number of lightning interruptions per 100 km per Ground Strike Density (GSD is measured in number of lightning strikes per km^2). This method has been used in several other studies[i, ii].

To obtain the GSD and length data, the FALLS™ software, from Global Atmospherics, Inc., was utilized. Current digitized feeder files, from other ComEd systems, were then imported into FALLS™. To determine the GSD, a 1-km buffer (the minimum detection efficiency of the National Lightning Detection Network (NDLN™) is 500m) was used around each of the feeders and an Asset Exposure Analysis was run. The Asset Exposure Analysis then returned the GSD (among other lightning statistics) for each of the feeders. A separate function returned the length of each feeder.

Lightning interruptions were extracted from ComEd's interruption database. The date range that was used for the analysis was from May 9, 1997 to September 9, 1998. This provided 15 months of data for the analysis. It also included data for 2 lightning seasons.

These outages were then analyzed, with the use of FALLS™, to determine if there was lightning present at the time of the reported outage. If there was lightning activity, up to 3 hours prior to the reported outage, then the outage was considered to be caused by lightning. The reason that the 3 hour time span was chosen was due to the methods for reporting outages, mainly customer calls, where a customer may not call in as soon as the outage occurs or they may not be able to get through right away, especially if there is a storm at the time.

Results

A descriptive statistical summary of the data, for just interruptions due to lightning, is shown in the following tables, Table 1 for the control group and Table 2 for the experimental group. This summary is for the filtered data (those outages that were considered to be caused by lightning). These tables show the average, minimum, maximum and standard deviation, of each group, for the number of interruptions due to lightning, the feeder length, the GSD and the number of interruptions per 100km per GSD. For the minimum and maximum statistics, the values for each measure are not necessarily for the same feeder.

Table 1

Control Group Statistics
For Interruptions Due to Lightning

	# of interruptions	Length (km)	GSD (#/km^2)	Interruptions/100km/GSD
Average	7.97	150.7	13.43	0.424
Minimum	0	36	6.70	0
Maximum	30	339	37.14	1.344
Standard Deviation	6.19	74.5	5.23	0.264

Table 2

Experimental Group Statistics
For Interruptions Due to Lightning

	# of interruptions	Length (km)	GSD (#/km^2)	Interruptions/100km/GSD
Average	6.07	183	13.47	0.246
Minimum	0	49	6.88	0
Maximum	16	345	19.68	0.481
Standard Deviation	3.89	81.16	3.25	0.120

A few observations can be made from this data. First, the length's of the experimental group are slightly longer than those of the control group. This is the case for the shortest and longest feeders within each group and for the average length. With all things being equal, the number of interruptions, due to any and all causes, on the experimental group would expected to be higher than that of the control group due to the increased exposure because of the greater length.

Next, the ground strike density (GSD) is about the same for both groups. This is especially true for the average and the minimum values. The big difference is in the maximum value, where the maximum GSD for the control group is almost twice as much as the experimental group. But, this difference in the maximum value of GSD is for only one (1) feeder and the rest of the feeders in the control group are in the same range as the experimental group. Therefore, if everything else were equal, then the number of interruptions due to lightning would expected to be roughly equal for each group.

As for the number of interruptions considered to be caused by lightning, the experimental group experienced fewer interruptions on average than the control group. Also, the maximum number for the experimental group was less than half of the control group. The only unexpected result is with minimum number of reported interruptions, where the control group value was the same as that of the experimental group. Even with the shorter minimum feeder length in the control group than the experimental group, the difference is not enough to explain this difference. Besides that, the feeders with the minimum reported interruptions were not on the shortest feeders.

Statistical analysis of the results indicates that there is sufficient evidence, at a 95% confidence level, to expect a 21% improvement in the lightning performance (in terms of the average number of interruptions per 100km per GSD) of the experimental group relative to the control group.

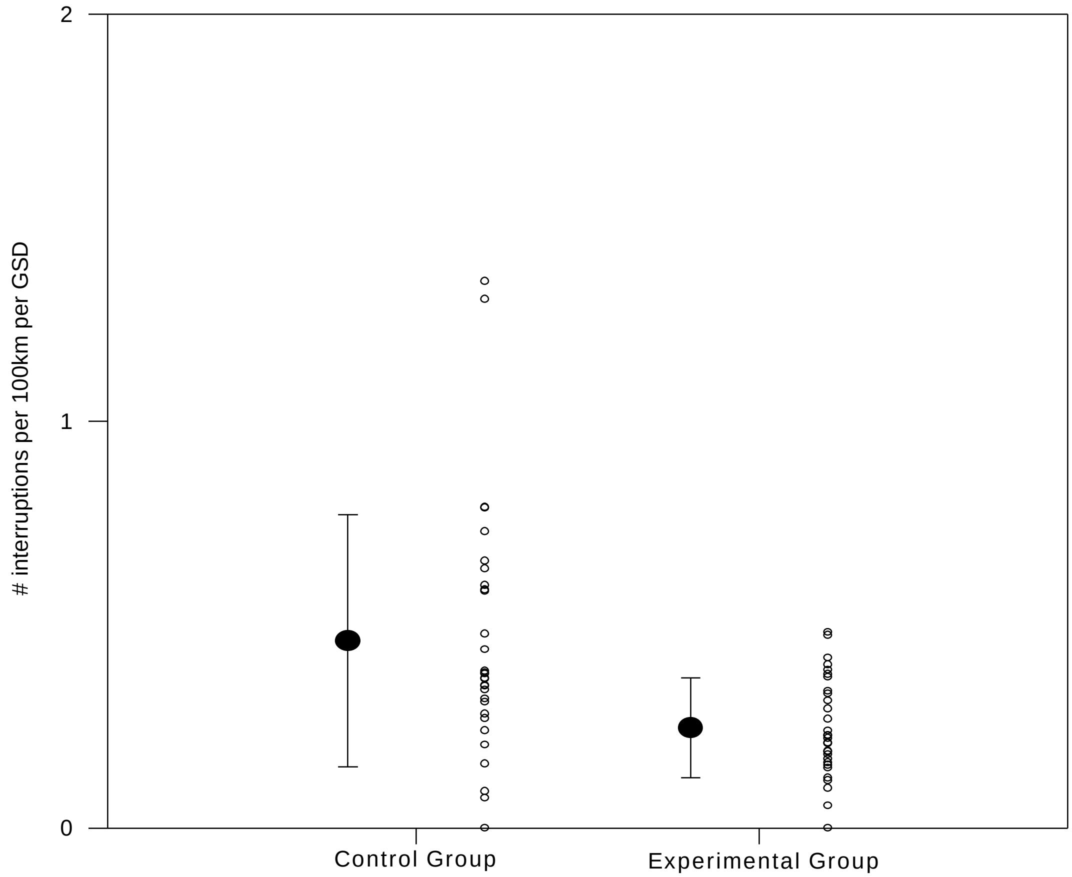
Discussion

Figure 1 shows a graphical representation of each feeder's number of interruptions/100km/GSD for both the experimental and control groups. The mean along with the plus/minus standard deviation for each group is also shown.

As shown in the graph, the control group has a much larger range than that of the experimental group. The control group also has 8 feeders whose number of interruptions/100km/GSD is higher than the maximum for the experimental group, with 2 of them almost 3 times greater. But on the other end, the control group's and the experimental group's minimum value are equal. Also, most of the experimental group's points are below the average of the control group. Those feeders that had higher numbers in the control group were expected since they were not upgraded to the current arrester standards, but those having same minimum value were not.

The mean for the control group is higher than that of the experimental group. The standard deviation for the control group is larger than that of the experimental group. The plus one standard deviation mark of the experimental group is lower than the mean of the control group. The minus one standard deviation mark of the experimental group is just slight less than that of the control group. The range of the experimental group is also much more compacted than that of the control group. All of these results were expected and they indicate an improvement of the experimental group over that of the control group.

Even though the experimental group performance has improved, on average, over that of the control group, the improvement was not as great as initially expected. However there was improvement in the performance. Of course, there are many reasons why the results were not as expected, or which the major reasons are trying to compare flashovers to sustained outages and the difference in the field conditions from those in the computer model.



The original study predicted a 70% improvement in the number of flashovers whereas this study is looking at sustained outages. Every feeder in this study is a rural circuit with multiple reclosers. With a recloser, a flashover would not necessarily lead to a sustained outage. The recloser would sense the flashover, open up, clear the flashover and then reclose and restore service. As there is no remote indication on these reclosers, there is no way to determine what the number of operations were, especially during thunderstorms, and therefore, no way to determine what the improvement in flashovers was for the experimental group.

Another factor that may have contributed to a lesser improvement might have been the field conditions versus the computer model. The model used for the computer simulations was a 3-phase main line circuit on 12m poles, while over 50% of the length of the experimental group circuits was single phase circuits with poles as short as 7.5m. While studies that were performed for the 34kV system showed that pole height affected the performance (a larger improvement for taller poles), no studies were conducted for 12kV, so it can only be inferred that with the shorter poles the improvement of the experimental group would have been slightly reduced. As the software that was used is no longer available, these field conditions cannot be put into the model to see what the revised expected performance would be.

As the feeders in this study have very minimal shielding, any lightning in the vicinity of the feeder should terminate on the feeder. If the lightning does not strike the feeder, it should strike far enough from the feeder so as not to induce a voltage that would cause a flashover. Therefore, any flashovers, or outages, on these feeders would be the result of a direct strike due to lightning.

Conclusions

There is an expected improvement in performance by installing arresters every 180m instead of every 360m. From the Field Test, there is an average improvement of 42%. However, statistical analysis shows a 21% improvement with a 95% confidence. The reason that the results of the Field Test were less than those predicted in the study is due to the assumptions that were used in the studies model. The greatest difference in the model from the field conditions was that the model used a 3-phase circuit on 12m poles and in the field over 50% of the circuits were single phase on poles as short as 7.5m. Also, the model was looking at flashovers, which do not necessarily lead to outages, and this study was looking at sustained outages.

Of course, the improvement in the performance of the experimental group was not as good as predicted. The original study expected a 70% improvement, but this improvement was in the number of flashovers per year, not sustained outages. At the time of the study and when the Field Test was proposed, the 70% improvement in flashovers was being equated to a 70% improvement in outages. With the number of reclosers on the circuits in the study, not every flashover would lead to a sustained outage. Without knowing the trip counts on all of the reclosers, there is no way of determining the improvement of the experimental group over the control group.

Even thought the performance of the new arrester standard was not as expected, there is still a benefit. With lightning being a leading cause of interruptions, a 21% improvement in performance can improve distribution reliability. This is especially important with the recent Illinois Commerce Commission Reliability Rulemaking, which in part specifies customer targets for reliability in terms of number of outages and length of outages.

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[i] T. A. Short and R. H. Ammon, "Monitoring Results of the Effectiveness of Surge Arrester Spacing on Distribution Line Protection," IEEE Transactions on Power Delivery preprint PE-422-PWRD-0-06-1998, June 1998.

[ii] J. Dougan, "Use of Lightning Flash Statistics Helps Utility Prioritize and Track Distribution Reliability Improvements," 1998 International Lightning Detection Conference.